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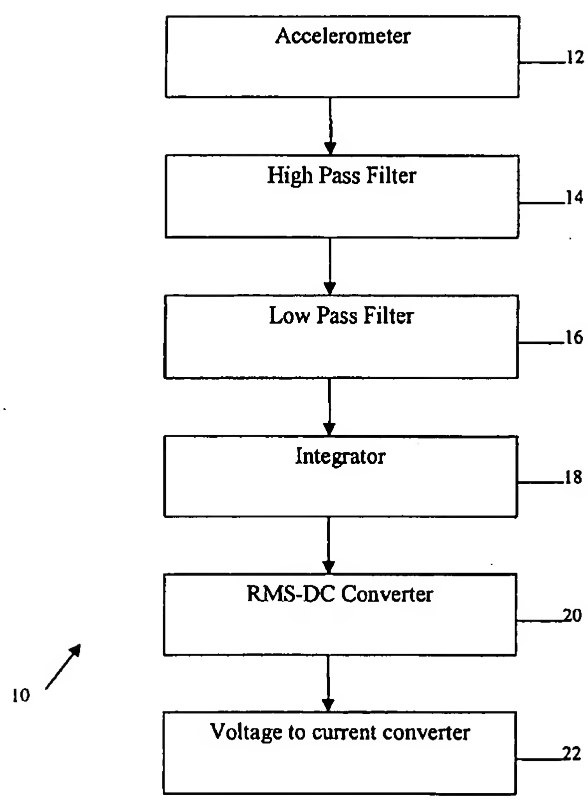
(54) Title: VIBRATION MEASUREMENT APPARATUS



(57) Abstract: A vibration measuring apparatus (10) inlcudes an accelerometer (12) which is contained within a surface micromachined integrated chip, and signal processing means including a high pass filter (14), a low pass filter (16) and an integrator (18).

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For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

TITLE

"VIBRATION MEASUREMENT APPARATUS"

Field of the Invention

The present invention relates to a vibration measurement apparatus.

The monitoring and analysis of the vibration of a machine can be a key means of assessing the condition of the machine, and predicting failure of certain components within the machine.

Various types of apparatus have been used to measure machine vibration. These include eddy current probes, moving element velocity pick-ups, and piezoelectric accelerometers. The most common type of apparatus used is a piezoelectric accelerometer.

There are several problems encountered with the use of piezoelectric accelerometers in measuring machine vibration. One problem is that of mass loading, whereby the mass of the accelerometer can distort the true vibration level of a structure. Another problem is that apparatus incorporating sensitive piezoelectric accelerometers is often large and expensive to manufacture, and therefore it is not always possible or economic to incorporate permanent vibration measuring devices into some machines.

The present invention attempts to overcome at least in part some of the aforementioned disadvantages of previous vibration measuring apparatus.

Disclosure of the Invention

In accordance with one aspect of the present invention there is provided a vibration measuring apparatus comprising an accelerometer and a signal processing means

arranged to receive a signal from the accelerometer and to produce an output signal, characterised in that the accelerometer is a contained within a surface micro machined integrated circuit chip.

Preferably, the signal processing means comprises a low pass filter, a high pass filter and an integrator.

Brief Description of the Drawings

The present invention will now be described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 is a flow chart representation of a vibration measuring apparatus in accordance with a first embodiment of the present invention;

Figure 2 is a flow chart representation of a vibration measuring apparatus in accordance with a second embodiment of the present invention;

Figure 3 is a flow chart representation of a vibration measuring apparatus in accordance with a third embodiment of the present invention; and

Figure 4 is a flow chart representation of a vibration measuring apparatus in accordance with a fourth embodiment of the present invention.

Description of the Invention

Referring to Figure 1, there is shown a conceptual representation of a vibration measuring apparatus 10. The vibration measuring apparatus 10 comprises an accelerometer 12, and a signal processing means comprising a high pass filter 14, a low pass filter 16, and an integrator 18.

The accelerometer 12 is constructed as part of a micro machined integrated circuit chip. A typical micro machined accelerometer 12 is comprised of a differential capacitor structure comprising two fixed plates and a moving plate supported by springs. Acceleration of the structure causes movement of the moving plate relative to the fixed plates. This movement causes a change in the capacitance of the structure, and can be measured as a change in the voltage measured across the accelerometer.

Micro machined accelerometers have been previously used for applications requiring the detection of a sudden acceleration or deceleration. These applications include automotive airbag actuation mechanisms. They have also been used in applications requiring tilt detection, such as in free air computer peripherals.

Previous attempts to use micro machined accelerometers in vibration monitoring applications have resulted in inaccurate results. It has now been discovered that accelerometer resonance is a substantial contributor to this inaccuracy. Circuit noise provides an additional source of inaccuracy.

A further contributor to this inaccuracy is that integration of an acceleration signal to form a velocity signal results in a low signal magnitude for higher frequencies. The acceleration response of a vibrating body at a particular frequency can be described by the equation

$$a = A\cos(2\pi ft)$$

Integration of this equation to obtain velocity gives

$$v = A/2\pi f \sin(2\pi ft)$$

The magnitude of the velocity signal thus decreases with an increase in frequency.

Attempts to magnify this signal volume have the effect of magnifying errors in the signal measurement, and also of magnifying the DC offset of the signal.

The present invention provides an alternative method for obtaining a velocity response at higher frequencies.

The accelerometer 12 is mounted to a machine so as to be able to generate a signal representing vibration of the machine. This signal, which may be deemed a raw signal, is typically an alternating voltage signal.

The raw signal typically comprises a combination of waveforms generated by the machine vibration, accelerometer resonance and ambient 'noise'.

The raw signal is input to the high-pass filter 14. The high-pass filter 14 acts to remove elements of the signal with frequencies below a predetermined level. In use, the high pass filter 14 acts to substantially decrease the ambient noise component of the signal. In a typical example, a high pass filter 14 with a lower frequency limit of 10Hz may be used to eliminate typical ambient noise which is below 10Hz.

The high pass filtered signal is then input to the low pass filter 16. The low pass filter 16 acts to remove elements of the signal with frequencies above a predetermined level. In use, the low pass filter 16 acts to remove that part of the signal associated with accelerometer resonance. Typically, accelerometer resonance occurs above 2kHz, and a low pass filter 16 with an upper frequency limit of 2kHz may be used to remove accelerometer resonance.

The filtered signal is then passed to the integrator 18 in order to convert the acceleration signal to a velocity signal according to the equation above. In a typical example, the integrator will include a DC gain of 1 at a frequency of 500Hz.

The use of a low resistor value in the high pass filter, typically approximately 100 kΩ, has the effect of reducing the DC voltage drop across the low pass filter to approximately 1mV, and the DC offset of the integrated signal to within a 1V range.

The velocity signal thus obtained represents the motion of the machine to which the vibration measuring apparatus 10 is coupled.

This velocity signal can be subject to a number of signal processing techniques according to particular needs identified.

In a first embodiment, as shown in Figure 1, the velocity signal (an alternating voltage signal) is fed to an RMS-DC converter 20 in order to obtain a single representative value for the machine vibration. The RMS-DC converter 20 converts the root mean square valve of the alternating voltage signal into a DC voltage. The magnitude of this DC voltage represents the amount of vibration the machine is undergoing.

The output of the RMS-DC converter 20 may then be converted to a current by a voltage to current converter 22 in order to be input into a programmable logic controller.

In a second embodiment, as shown in Figure 2, the signal from the RMS-DC converter 20 is transmitted directly to a display device 24. The display device 24 may be in the form of a series of lights such as light emitting diodes. The display device 24 may be arranged so that the number of lights displayed may correspond to particular levels of signal received from the RMS-DC converter 20. The lights may be of different colours.

A third embodiment of the present invention is shown in Figure 3. In this embodiment the vibration measuring apparatus 10 further includes a temperature measuring portion 26. The temperature measuring portion 26 includes a temperature sensor 28, an amplifier 30 and a second voltage to current converter 32.

In use, the output from the temperature sensor 28 is amplified by the amplifier 30 and converted to a current by the second voltage to current converter 32. This signal can then be input into a programmable logic controller.

A fourth embodiment of the present invention is shown in Figure 4. In this embodiment the signals from the RMS-DC converter 20 and the amplifier 30 are fed to a multiplexer 34. In this embodiment the multiplexer 34 controls the display device 24, and may be arranged to alternately display information concerning the vibration and the temperature being measured.

It will be appreciated that when a display device 24 is used then the vibration measuring apparatus 10 may be battery operated and therefore completely self contained. It may be arranged to have a switching arrangement so that the vibration measuring apparatus 10 is only operative when a user depresses a switch.

Further embodiments are also envisaged. For instance, the velocity signal or acceleration signal may be subjected to spectral analysis in order to identify particular sources of vibration.

Modifications and variations as would be apparent to a skilled addressee are deemed to be within the scope of the present invention. For instance, the signal processing means may comprise digital or analog signal processing components or a combination of digital and analog signal processing components. Further, diagnostic components and analysis may be added to the vibration measuring apparatus 10 in order to diagnose particular machine faults. These components may be integrated onto a single chip. This may be done by means of large scale integration. The information thus obtained may then be communicated by communication means such as computer networks or wireless communication means to a remote location. It will

also be appreciated that more than one accelerator may be used, for instance in order to measure vibration on more than one axis.

CLAIMS

1. A vibration measuring apparatus comprising an accelerometer and a signal processing means arranged to receive a signal from the accelerometer and to produce an output signal, characterised in that the accelerometer is contained within a surface micro machined integrated chip.

2. A vibration measuring apparatus as claimed in Claim 1, characterised in that the signal processing means comprises a high pass filter.

3. A vibration measuring apparatus as claimed in Claim 2, characterised in that the high pass filter is arranged to remove frequencies below 10Hz.

4. A vibration measuring apparatus as claimed in Claim 2 or Claim 3, characterised in that the high pass filter incorporates a resistor value of approximately 100kΩ.

5. A vibration measuring apparatus as claimed in any one of the preceding claims, characterised in that the signal processing means comprises a low pass filter.

6. A vibration measuring apparatus as claimed in Claim 5, characterised in that the low pass filter is arranged to remove frequencies above 2kHz.

7. A vibration measuring apparatus as claimed in any one of the preceding claims, characterised in that the signal processing means comprises an integrator.

8. A vibration measuring apparatus as claimed in Claim 7, characterised in that the integrator has a DC gain of about 1 at a frequency of 500Hz.

9. A vibration measuring apparatus as claimed in Claim 1, characterised in that the signal processing means comprises a high pass filter, a low pass filter and an integrator.

10. A vibration measuring apparatus as claimed in Claim 9, characterised in that the signal is arranged to pass in turn through the high pass filter, the low pass filter and the integrator.

11. A vibration measuring apparatus as claimed in Claim 9 or Claim 10, characterised in that the signal processing means further includes an RMS-DC converter.

12. A vibration measuring apparatus as claimed in Claim 11, characterised in that the signal processing means further includes a voltage to current converter.

13. A vibration measuring apparatus as claimed in any one of the above claims, characterised in that the vibration measuring apparatus further includes a display device arranged to display the output signal.

14. A vibration measuring apparatus as claimed in Claim 13, characterised in that the display device is a series of lights.

15. A vibration measuring apparatus as claimed in any one of the preceding claims, characterised in that the vibration measuring apparatus further includes a temperature measuring portion.

16. A vibration measuring apparatus as claimed in any one of the preceding claims, characterised in that the vibration measuring apparatus is selectively operative by way of a switch.

17. A vibration measuring apparatus as claimed in any one of the preceding claims, characterised in that the signal processing means is comprised of digital components.

18. A vibration measuring apparatus as claimed in any one of Claims 1 to 16, characterised in that the signal processing means is comprised of analogue components.

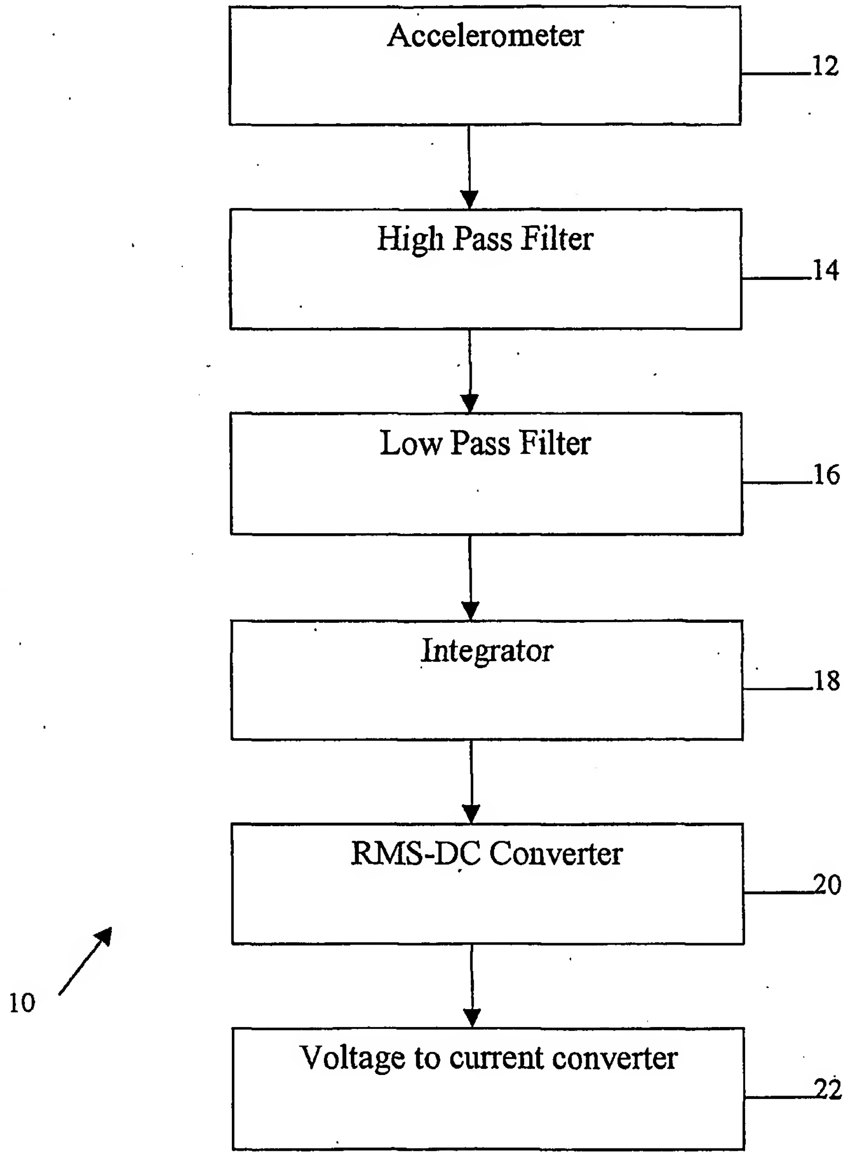
Accelerometer
12
High Pass Filter
14
Low Pass Filter
16
Integrator
18
RMS-DC Converter
20
Voltage to current converter
22
10

Figure 1

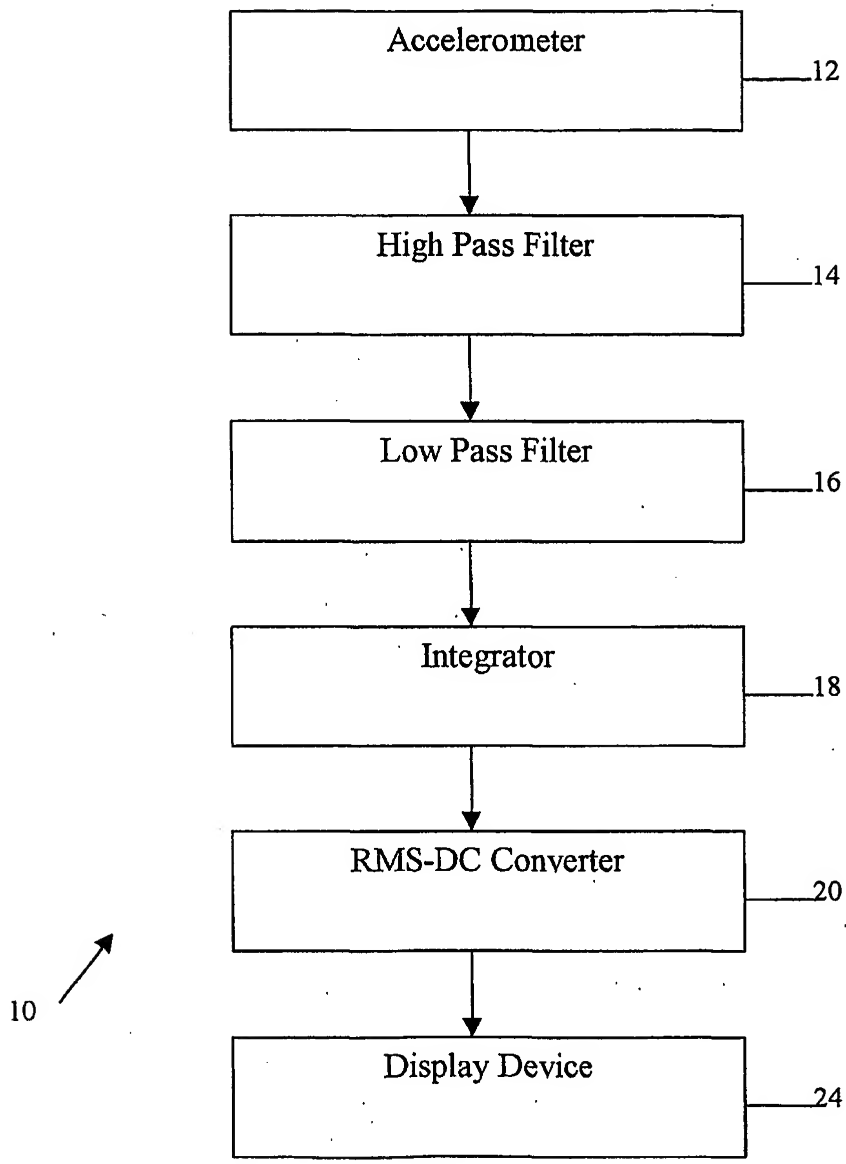
Accelerometer
12
High Pass Filter
14
Low Pass Filter
16
Integrator
18
RMS-DC Converter
20
10
Display Device
24

Figure 2

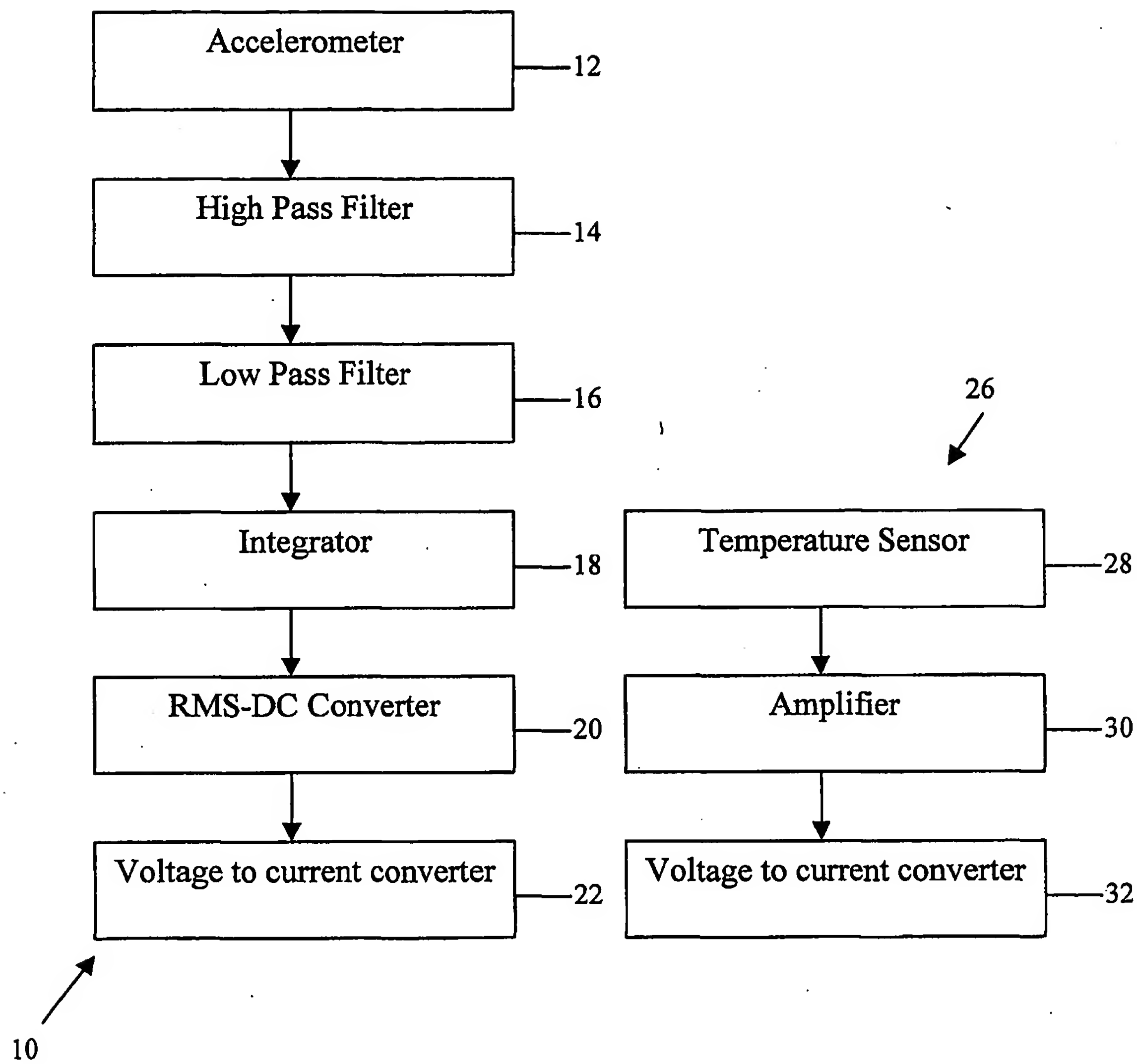
Accelerometer
12
High Pass Filter
14
Low Pass Filter
16
Integrator
18
RMS-DC Converter
20
Voltage to current converter
22
10
26
Temperature Sensor
28
Amplifier
30
Voltage to current converter
32

Figure 3

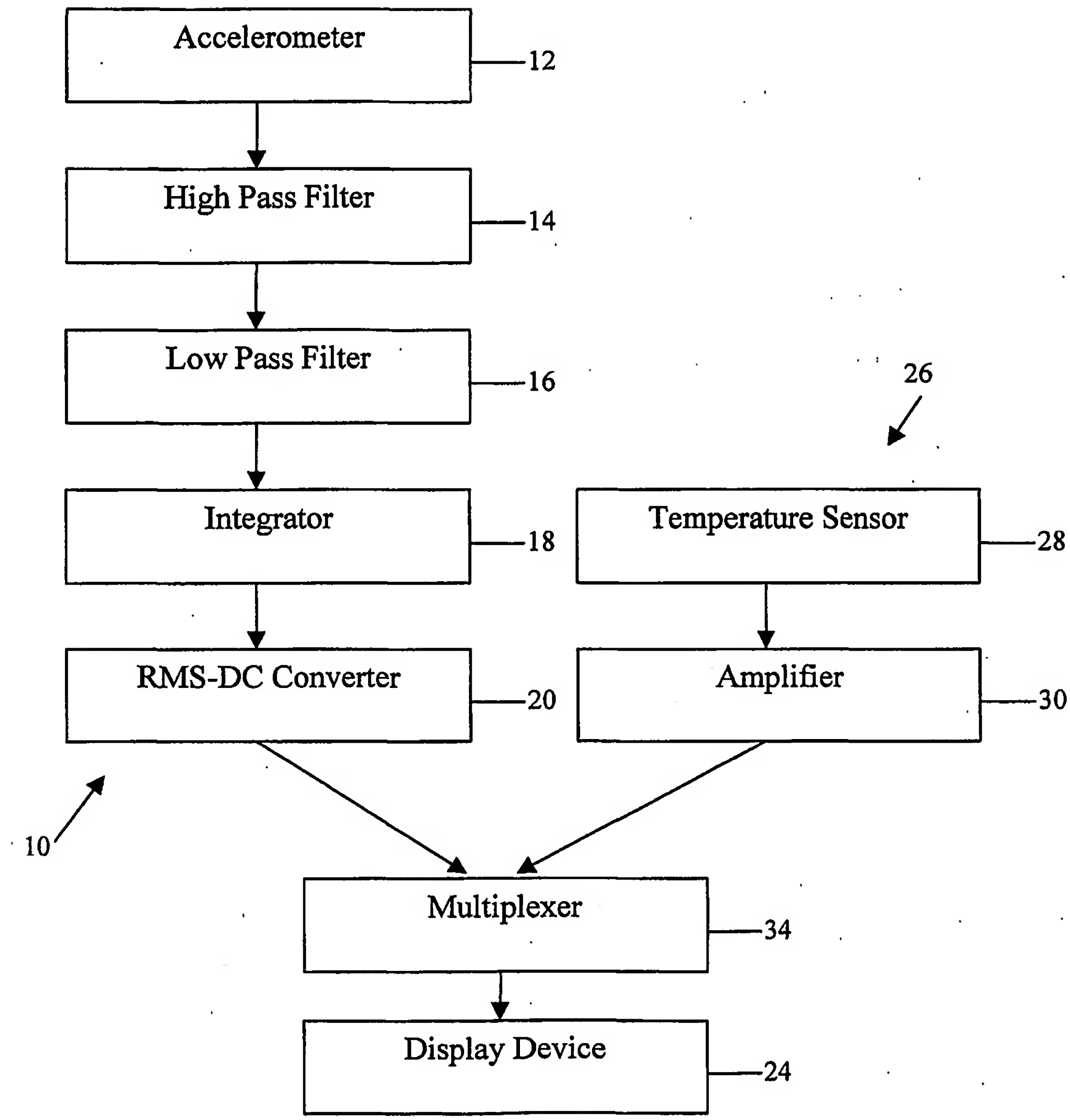
Accelerometer
12
High Pass Filter
14
Low Pass Filter
16
26
Integrator
18
Temperature Sensor
28
RMS-DC Converter
20
Amplifier
30
10
Multiplexer
34
Display Device
24

Figure 4

INTERNATIONAL SEARCH REPORT

International application No.
PCT/AU02/00181

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl. [7]: G01P 15/08, G01H 11/06

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
DWPI :- (G01P 15/-, 7/-, G01h 1/-, 11/- OR accelerometer+ or (vibration (s)sens+)) and micromachin+ and (signal process+, low pass, high pass, filter etc)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
P,X	US 6196067 B1 (Martin et al) 6 March 2001 See the abstract	1-18
X	EP 798015 A2 (SULZERmedica) 1 October 1997 See the abstract, col 3 line 20-32	1-18
X	EP 772045 B1 (Delphi Technologies, Inc) 13 December 2000 see col 11 lines 26-40, claim 1	1-18

[X] Further documents are listed in the continuation of Box C [X] See patent family annex

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
10 April 2002	1 MAY 2002
Name and mailing address of the ISA/AU AUSTRALIAN PATENT OFFICE PO BOX 200, WODEN ACT 2606, AUSTRALIA E-mail address: pct@ipaustralia.gov.au Facsimile No. (02) 6285 3929	Authorized officer I.A.BARRETT Telephone No : (02) 6283 2189

INTERNATIONAL SEARCH REPORT

International application No.
PCT/AU02/00181

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 01/00523 A1 (Regents of the University of Minnesota) 4 January 2001 See the abstract	1-18
X	WO 96/42111 A1 (Regents of the University of California) 27 December 1996 See the abstract, page 11 line 16-27	1-18
X	US 5001933 A (Brand) 26 March 1991 See the abstract	1-18
X	US 4932261 A (Henrion) 12 June 1990 See the abstract, col 2 line 55-64	1-18
X	US 4918032 A (Jain et al) 17 April 1990 See the abstract	1-18
X	Derwent Abstract Accession No.89-239750/33, Class P54, SU 1458088 A, (Urals Kirov Poly) 15 February 1989 See the abstract	1-18
X	US 5550090 A (Ristic et al) 27 August 1996 See the abstract, col 1 line 14, col 2 line 31-49	1-18